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Identification of Transient Voltage Noise Sources

Prepared by: Jim Lepkowski
ON Semiconductor

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APPLICATION NOTE

INTRODUCTION

One of the first steps required to solve an EMI problem is to identify the noise source. Identifying the noise source provides the information needed to predict the damage potential of the surge voltage. Knowledge of the noise source can be used to select an appropriate suppression circuit. This document provides guidelines to estimate the magnitude, duration, energy and frequency of several common noise sources that result from conduction and coupling between power and data lines.

Transient voltage surges are a major contributor to the early failure of semiconductors and other sensitive electrical components. In addition, voltage surges can cause erratic behavior in control circuits because the system may not be able to distinguish a legitimate signal from a surge induced signal. Transient Voltage Suppression (TVS) devices can be used to suppress surge pulses and increase the reliably of a system without significantly adding to the cost and complexity of the circuits.

Problem Definition

The noise source−path−receptor model shown in Figure 1 can be used to identify EMI problems. A noise source, receptor and coupling path must be present in order for EMI to become a problem. The noise source produces the energy that will disturb the operation of the receptor when a coupling path exists between the source and receptor.

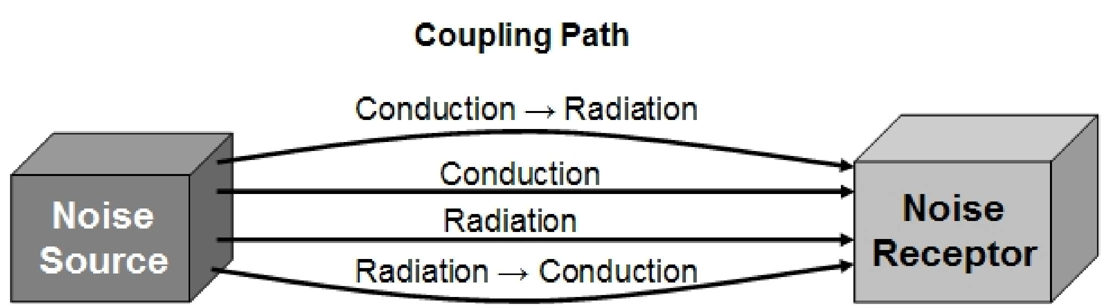


Figure 1. The Noise Source−Path−Receptor EMI Model

Table 1 provides a summary of the techniques that can be used to suppress conduction and radiation noise sources. EMI filters and TVS devices are used to solve conduction problems, while shielding is used for radiation or RF suppression. In many applications, a combination of suppression techniques is required to build a robust system with a high noise immunity level.

Table 1. Techniques to Suppress Conducted and Radiated Noise

Noise Source	Suppression Techniques	
	At Source	At Receiver
Conduction	EMI Filters TVS Devices	EMI Filters TVS Devices
Radiation	Shielding	Shielding
Conduction → Radiation	EMI Filters TVS Devices	Shielding
Radiation → Conduction	Shielding	EMI Filters TVS Devices

Common Electrical System EMI Sources

Transient surge voltages result from the sudden release of stored energy. EMI transients can usually be attributed to:

- Power source fluctuations
- Sudden load changes
- Short circuits
- Opening or closing of switch contacts
- Coupled electronic disturbances via cables
- Inductive switching
- Lightning
- ESD

The power supply and data cables are usually the main entry points for transient surge voltages. In many systems a common power supply is shared by a number of electronic modules as shown in Figure 2. The voltage surges produced by inductive loads such as motors or relays can effect the operation of electronic modules that share the same power. In addition, the power and data lines are often located in the same wire bundle. The parasitic cable capacitances and inductances create a path for the surge voltages produced on the power lines to be coupled into the data lines.

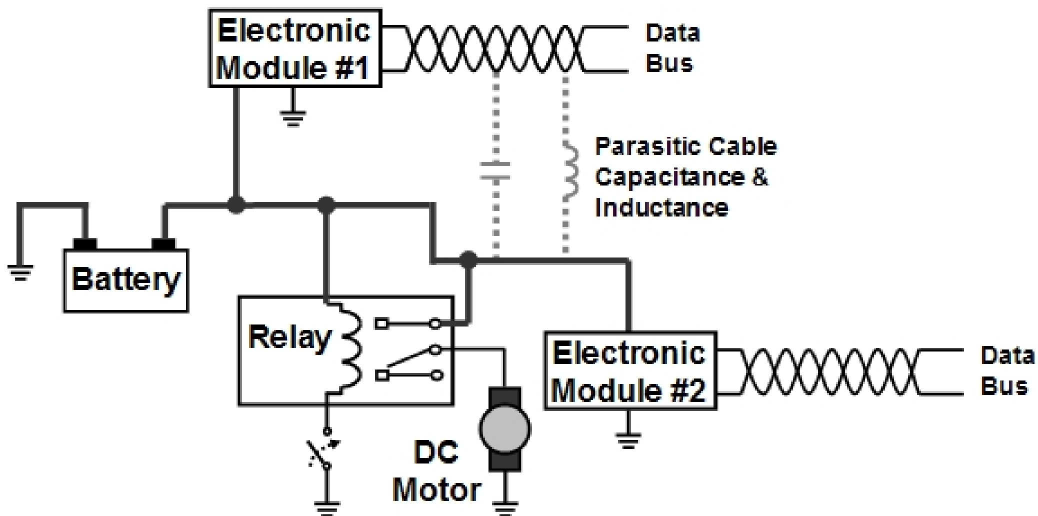


Figure 2. External system noise can easily enter an electronic module from conduction and coupling via the power supply and data cables.

An input/output (I/O) connector is used to provide the interface between the internal PCB circuits and the external modules. The power and data lines that are exposed to external noise sources typically enter the PCB at the I/O connector; thus, TVS surge protection must be provided at the connector. Locating the TVS devices close to the connector helps to suppress the surge pulse from being coupled into adjacent traces on the PCB.

The noise sources located on the PCB must also be analyzed in addition to the external noise sources located outside the electronic module. Figure 3 provides an example of noise sources located on a PCB. Common examples of PCB noise sources include switched mode power supplies (SMPS), digital logic ICs, data clocks and high current load driver circuits. The N− and P−channel stacked configuration used in CMOS ICs is an example of an often neglected noise source. A CMOS IC’s power supply is shorted to ground during the transition time when both transistors are turned−on, producing a high shoot−through current. This problem is typically solved with a decoupling capacitor; however, a surge voltage will be produced on the power line if the capacitance is inadequate.

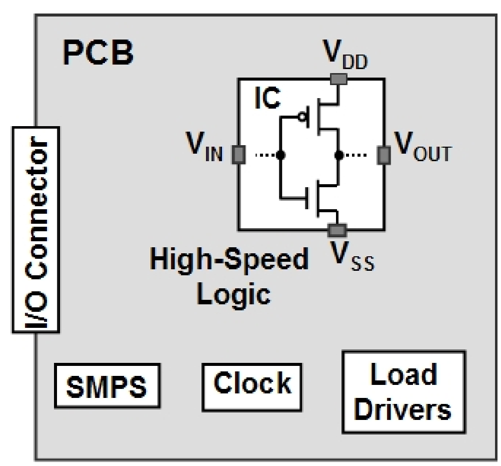


Figure 3. Common PCB Noise Sources

The immunity level required to protect against surge voltages will vary for each application. The automotive noise sources shown in Table 2 provide an example of the transients that can be expected to occur in a DC powered system. For other applications, EMI test standards such as the IEC 61000−4 [2] specification can be used as a baseline to define the surge immunity level needed to build a robust product.

Table 2. Typical Automotive Transients

Noise Source	Length of Transient	Energy	Voltage Amplitude	Occurrence
Load Dump	200 to 400 ms	> 10 J	+60 to +125 V	Infrequent
Inductive Load Switching	< 300 μs	< 1 J	−300 to +80 V	Often
Alternator Field Decay	200 ms	< 1 J	−100 to −40 V	Every Turn−off
Mutual Coupling in Wiring Harness	1.0 ms	< 1 J	< ±200 V	Often
ESD	< 50 ns	<10 mJ	8.0 kV (Contact) 15 kV (Air Discharge)	Infrequent

EMI Immunity Tests

Electronic systems must be able to survive the high energy transients that are produced by non−repetitive and repetitive transient surge voltages, lightning and ESD. The definition of non−repetitive and repetitive surges is determined by the duration of the transient and the time between surges. A non−repetitive surge can be defined as a transient voltage with a pulse width of typically 50 to 2000 μs and a repeat rate of usually one pulse per second. Repetitive surges are represented by a burst of 15 to 300 ms of 50 ns transient pulses. Examples of non−repetitive noise sources include lightning, load dump, power switching, load changes and short circuit faults. Repetitive noise sources include inductive load switching, relay contact chatter and ignition system noise.

Pass/Fail Test Criteria

The pass/fail criterion of an EMI test is determined by both the operational status of the system and if any damage occurs to the circuits. In some systems a fault is allowed during the EMI test surge; however, normal operation must resume after completion of the transient event. The test criteria can also be defined by the maximum surge voltage that the system can be guaranteed to withstand without being damaged.

Non−Repetitive Surge Immunity

The non−repetitive surge tests are used to test a module's transient immunity from noise sources such as power switching, sudden load changes or a short circuit fault in the power distribution system. A DC motor is an example of a noise source that can produce a single surge pulse when power is removed because the motor continues to rotate for a short duration because of inertia.

Repetitive Surge Immunity

The repetitive or electrical fast transients (EFT) surge tests are used to test a module's transient immunity from noise sources such as inductive load switching, relay contact chatter and ignition system noise. Repetitive switching transients are typically coupled into the wiring harness because of the cable's parasitic capacitance and inductance.

Figure 4 provides an example of a MOSFET load driver circuit that can produce a burst of short duration, high voltage surge pulses. The surge pulses can be suppressed using a free−wheeling diode (D_1) or an avalanche TVS diode (Z_1). Diode D_1 or Z_1 is required because the parasitic drain−to−source Zener diode inherent in a MOSFET typically has a poor surge rating.

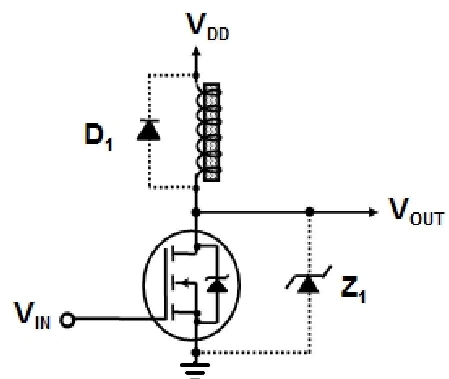


Figure 4. A low−side driver is an example of a circuit that can produce a repetitive burst of high frequency, short duration surge pulses.

Lightning

Lightning produces a transient surge voltage that can cause significant damage to an electronic system through either a direct or an indirect strike. A direct lightning strike requires a very high energy TVS device such as a gas discharge tube protection circuit. The indirect strike produces an intense electric and magnetic field that is coupled into the data and power lines, producing a large surge voltage. The magnitude of an indirect strike depends on the distance from the lightning strike and typically the energy is low enough that it can be absorbed by a TVS Zener diode.

ESD

The ESD immunity level can be specified by several different tests. ICs typically use the human body model (HBM) and machine model (MM) tests, while system level tests use the IEC 61000−4−2 specification. The HBM and IEC ESD specifications are designed to simulate the direct contact of a person to an object such as the I/O pin of a connector; however, the IEC test is more severe than the HBM. The IEC test is defined by the discharge of a 150 pF capacitor through a 330 Ω resistor, while the HBM uses a 100 pF capacitor and 1500 Ω resistor. In contrast, the MM test is intended to model an ESD event that can occur during the PCB assembly process.

EMI Noise Sources

The ISO 7637 EMI specification can be used as a guideline to identify the pulse characteristics of common noise sources found in a DC system [3],[4]. ISO 7637 defines the conducted immunity requirements for automotive and trucks; however, many other industries also have load switching and inductive loads. The transient voltages produced by noise sources such as motors or relays will be similar and the ISO specification can be used as a starting point to estimate the surge immunity requirements. In addition, the ISO tests can measure the reliability of a system by performing the tests for an extended time period with multiple surge pulses. Reference [5] provides a study showing that the ISO 7637 specification is representative of the surge voltages measured on a bus.

ISO 7637−2, Test Pulse 1

Figure 5 shows a schematic of the condition that generates a surge pulse when power is removed from an inductive load. The device under test (DUT) remains connected in parallel with the inductance. This produces a negative voltage as shown in Figure 6. DC motors, solenoids and relays are common examples of inductive loads that are often connected in parallel with an electronic module.

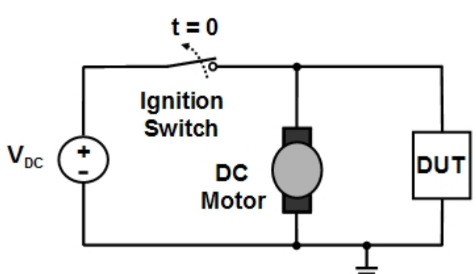
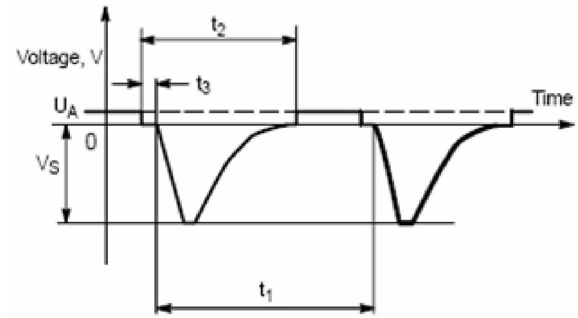


Figure 5. A high energy negative surge pulse is produced when power is removed from an inductive load, such as a DC motor, that is in parallel with an electronic module. This test case is simulated by pulse 1 of ISO 7637−2.



V_S = −75 to −100 V
U_A = 13.5 V
R_i = 10 Ω
t_d = 2000 μs
t_r = 1.0 μs
t_1 = 0.5 to 5.0 s
t_2 = 200 ms
t_3 < 100 μs

Figure 6. ISO 7637−2, Pulse 1 Waveform

ISO 7637−2, Test Pulse 2a and 2b

Test pulses 2a and 2b correspond to positive voltage transients that are created due to the sudden interruption of current in a load that is connected in parallel with an electronic module. Low−side drivers that are used to turn−on electronic modules, motors and relays are examples of systems that can produce the surge pulses simulated by pulse 2a and 2b. The pulse 2a and 2b test configurations, shown in Figures 7 and 8 respectively, simulate the transients that occur due to the inductance of the wiring harness. The pulse 2a test models the case when the load switch opens while power is applied to the load. In contrast, the pulse 2b test measures the response when a load such as a motor is running and power is disconnected. The test waveforms are shown in Figures 9 and 10. Figure 11 shows the voltage suppression capability of the NUP2105L TVS Zener diode for the pulse 2a test.

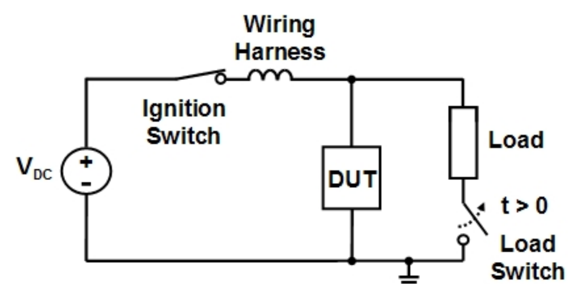


Figure 7. Test pulse 2a of ISO 7637−2 represents the surge produced by the inductance of the wiring when power is removed from a load that is connected in parallel with an electronic module.

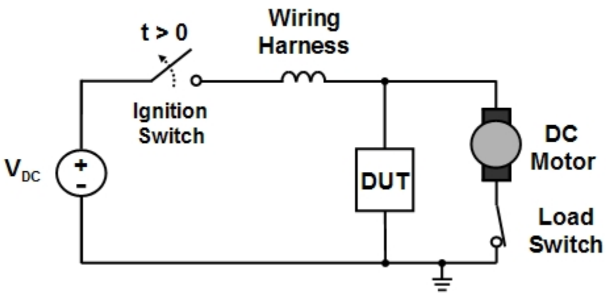
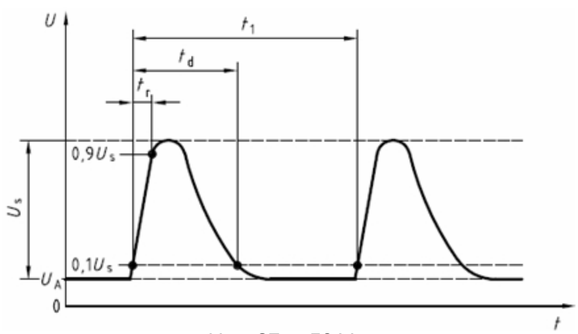
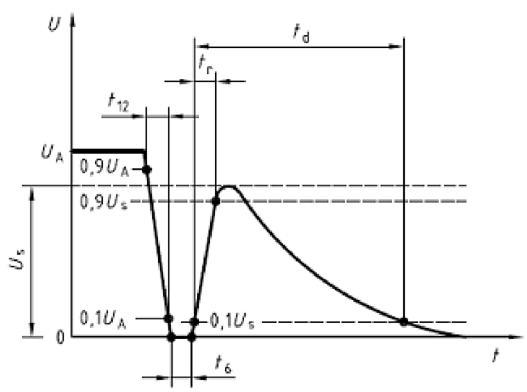


Figure 8. Test pulse 2b of ISO 7637−2 represents the surge produced by the inductance of the wiring when power is removed from both the parallel load and the electronic module.



U_S = 37 to 50 V
U_A = 13.5 V
R_i = 2.0 Ω
t_d = 50 μs
t_r = 1.0 μs
t_1 = 0.2 to 5.0 s

Figure 9. ISO 7637−2, Pulse 2a Waveform



U_S = 10 V
R_i = 0 to 0.05 Ω
t_d = 0.2 to 2.0 s
t_{12} = 1.0 ms
t_r = 1.0 ms
t_6 = 1.0 ms

Figure 10. ISO 7637−2, Pulse 2b Waveform

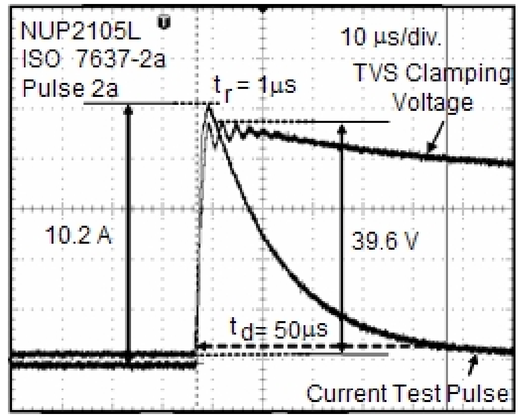


Figure 11. Test Response of the NUP2105L to the Pulse 2a Waveform

ISO 7637−3, Test Pulse 3a and 3b

Test pulses 3a and 3b simulate the switching noise produced by a switching process that is influenced by the parasitic capacitance and inductance of the wire harness. Relay and switch contact bouncing are two examples of noise sources that produce a short burst of high frequency pulses. The ISO 7637−3 test is similar to the −2 test, except that the −3 test is intended for data lines while the −2 test is for power lines. Figure 12 shows a schematic of the pulse 3a and 3b test configuration. The pulse 3a test has a negative waveform, as shown in Figure 13. Figure 14 shows the positive waveform of the pulse 3b test. The 3a and 3b pulses are also termed as the electrical fast transient (EFT) tests.

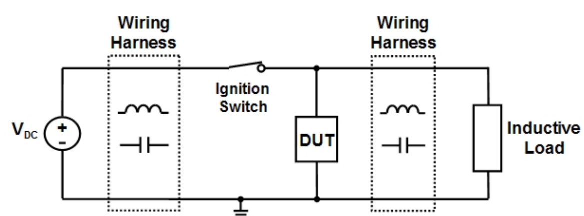
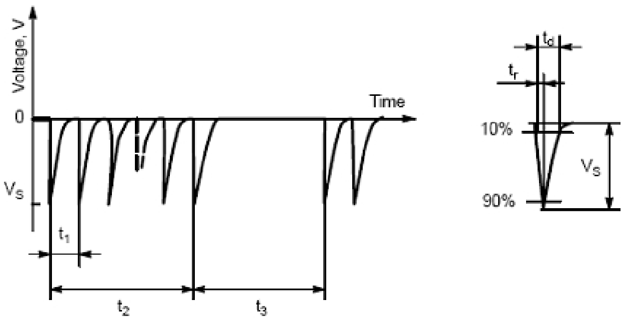
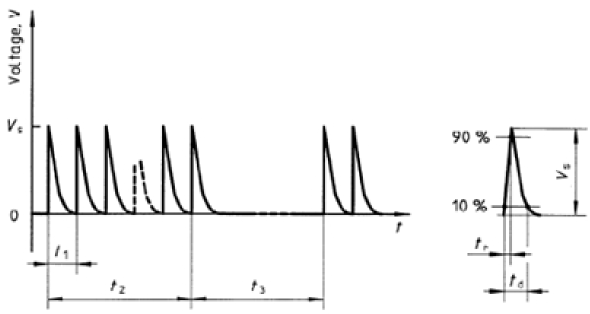


Figure 12. The ISO 7637−3 pulse 3a and 3b tests simulate the voltage transients that are produced by load switching, and the parasitic wire inductance and capacitance.



$V_S = -60$ V
$R_i = 50\ \Omega$
$t_d = 0.1\ \mu s$
$t_r = 5.0$ ns
$t_1 = 100\ \mu s$
$t_2 = 10$ ms
$t_3 = 90$ ms

Figure 13. ISO 7637−3, Pulse 3a Waveform



$V_S = 40$ V
$R_i = 50\ \Omega$
$t_d = 0.1\ \mu s$
$t_r = 5.0$ ns
$t_1 = 100\ \mu s$
$t_2 = 10$ ms
$t_3 = 90$ ms

Figure 14. ISO 7637−3, Pulse 3b Waveform

ISO 7637−2, Test Pulses 5a and 5b

Figure 15 shows an example of the "load dump" test that occurs if the battery is disconnected from the alternator while the engine is running. Waveforms of the 5a and 5b test pulses are shown in Figures 16 and 17. The amplitude and duration of the load dump pulse varies from a number of factors, such as the speed of the alternator and the level of the field excitation when the battery is disconnected. The unsuppressed 5a pulse is typically the highest energy and most serve surge test in an automotive application. In some vehicles, the load dump amplitude is limited by a clamping device that is located inside the alternator. The pulse 5b waveform is used for a suppressed system. Automotive systems are often tested per load dump specifications that are different than the ISO 7637 specification. Many systems require the pulse 5a test to have a surge magnitude of 120 V, while 35 V is a typical value for the suppressed pulse 5b test.

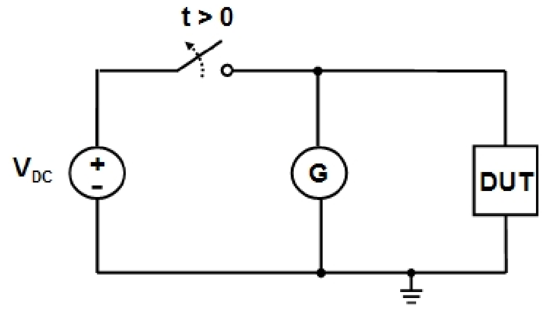
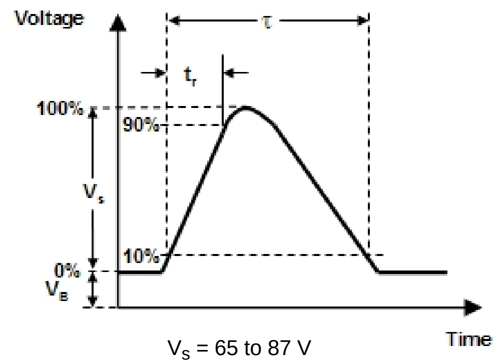
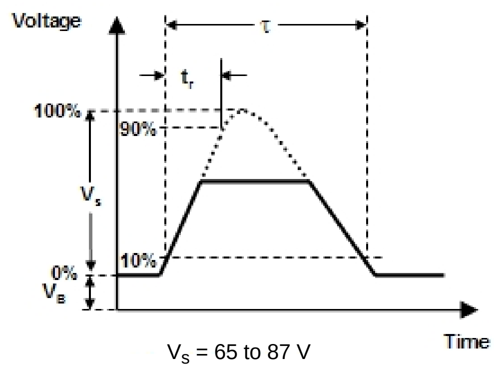


Figure 15. The load dump test simulates the surge voltages produced on a power supply line if the alternator is disconnected while the battery is being charged.



$V_S = 65$ to 87 V
$V_B = 14$ V
$R_S = 0.5$ to $4.0\ \Omega$
$t_r = 5.0$ to 10 ms
$\tau = 40$ to 400 ms

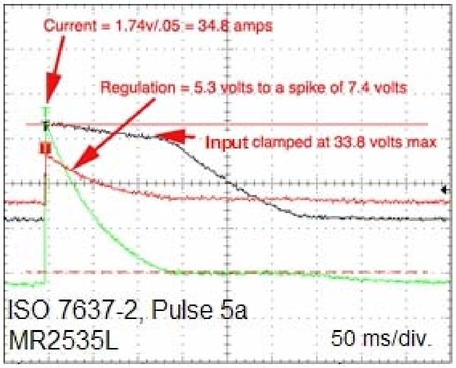
Figure 16. ISO 7637−2, Pulse 5a Waveform



$V_S = 65$ to 87 V
$V_B = 14$ V
$R_S = 0.5$ to $4.0\ \Omega$
$t_r = 5.0$ to 10 ms
$\tau = 40$ to 400 ms

Figure 17. ISO 7637−2, Pulse 5b Waveform

A TVS avalanche diode can be used to provide load dump protection. Figure 18 shows that the MR2535L TVS diode provides approximately 35 A of load dump protection to a linear voltage regulator.



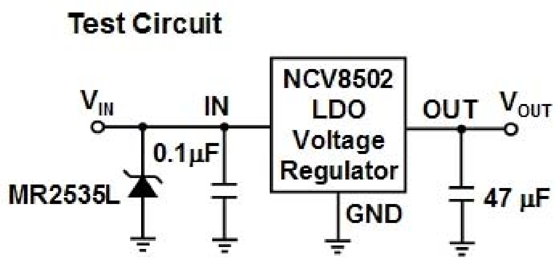


Figure 18. Test Response of the MR2535L and NCV8502 to the Pulse 5a Waveform

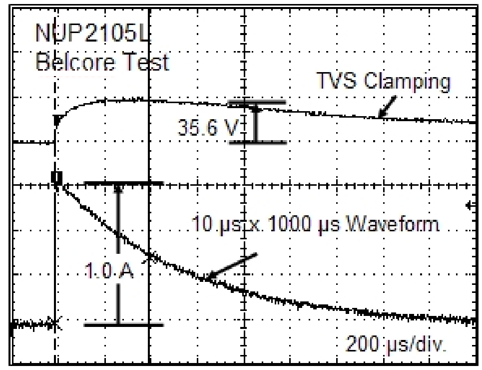


Figure 19. Test Response of the NUP2105L to the 10 x 1000 μs Waveform

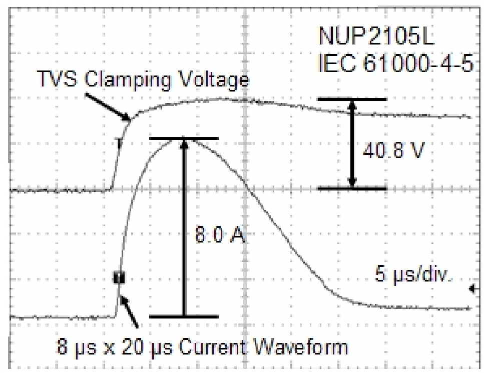


Figure 20. Test Response of the NUP2105L to the 8 x 20 μs Waveform

Lightning Protection

The lightning protection immunity level provided by a TVS device can be defined by both a long 10 μs x 1000 μs and a short 8.0 μs x 20 μs pulse. Primary systems that are directly exposed to lightning, such as outdoor telephone lines, typically use the 10 μs x 1000 μs pulse to define their immunity level. The shorter 8.0 μs x 20 μs pulse is often used for secondary systems, such as the wiring inside a building that is located down stream from a primary system.

The 10 μs x 1000 μs surge test, shown in Figure 19, is often termed as the Bellcore GR−1089 CORE test and is popular in telecommunication applications. The surge voltage waveform is defined by a double exponential pulse with a specified rise time (t_r) of 10 μs and duration (t_d) of 1000 μs. The IEC 61000−4−5 specification defines the 8.0 μs x 20 s test pulse, shown in Figure 20. The NUP2105L has a rating of 1.0 A and 10 A for the 10 μs x 1000 μs and 8.0 x 20 μs tests, respectively.

ESD Tests

Many EMI specifications require an ESD rating of at least 8.0 kV; however, an immunity level of greater than 30 kV can be provided by a TVS device. It is often difficult to quantify the immunity level required by a system because ESD can produce gradual changes to the impedance of an I/O circuit. The circuit may continue to operate with ESD damage and a complete failure may not show up until after an extended time. The NUP2105L TVS diode has an IEC contact rating of 30 kV, a level which will prevent ESD failures. Table 3 provides a summary of the ESD rating of the NUP2105L.

Table 3. ESD Rating for the NUP2105L

ESD Test	NUP2105L Test Results
IEC 61000−4−2 Contact Non−Contact (Air)	 ≥ ±30 kV ≥ ±30 kV
Human Body Model (HBM)	16 kV
Machine Model	400 V

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